A FEASIBILITY STUDY FOR A BACKUP FLIGHT CONTROL SYSTEM FOR THE A7A/B AIRCRAFT

Richard Jeffrey Miles

United States

Naval Postgraduate School

THESIS

A FEASIBILITY STUDY FOR A BACKUP FLIGHT CONTROL SYSTEM FOR THE A7A/B AIRCRAFT

by

Richard Jeffrey Miles

Thesis Advisor: Donald M. Layton

September 1971

A Feasibility Study for a Backup Flight
Control System for the A7A/B Aircraft

by

Richard Jeffrey Miles
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1971

ABSTRACT

The hinge moments for the A7A/B unit horizontal tail (UHT) were computed for a range of airspeeds and altitudes representative of the Southeast Asia combat environment. Electrical power available from the aircraft generator and the emergency power package was determined. The horsepower required to overcome the maximum hinge moment of the UHT was calculated and compared with power available from the aircraft generator and the emergency power package in order to ascertain whether an electrical motor could control UHT movement.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author wishes to thank Professor Donald Layton for his ideas and assistance; Lieutenant Commander Charles C. Cromer, Naval Plant Representative Office, LTV Aerospace Corporation, for his liaison work between the author and LTV; and finally Mr. W. C. Heald of LTV Aerospace Corporation for his knowledgeable advice and for forwarding the LTV engineering documents which made this study possible.

I. INTRODUCTION

In the Southeast Asia conflict over 1000 fixed-wing aircraft have been lost to hostile ground fire. Some aircraft sustained catastrophic damage and would have been unflyable regardless of the type of flight control system installed. However, a sizeable number of aircraft were lost due to relatively minor damage to the hydraulic flight control system. A general exception to this was the McDonnell-Douglas A-4, in various models, which on occasion sustained fifteen square foot holes, or larger, completely through the wing with immediate massive hydraulic failure. Even with the severe degradation of flying qualities, the aircraft and pilot were often recovered aboard ship because of a manual backup flight control system. Even if landing was not possible the pilot was usually able to make it to a "safe" ejection area.

With the present heavy, long fuselage, large control surface aircraft, it is not possible for a pilot to control the aircraft at high maneuvering speeds without a power boost of some sort. Aircraft in this category generally employ single-path mechanical linkages to dual hydraulically powered actuators. There are areas in the fuselage and at the actuators themselves where the two hydraulic systems must come into close proximity. At these vulnerable places a single, small-arms round has caused dual hydraulic failure, loss of control, and subsequent loss of life or capture of the crew by unfriendly forces. An attempt to alter the last outcome motivated this study.[1,2]

II. A7A/B HYDRAULIC FLIGHT CONTROL SYSTEM

In the A7A/B aircraft, irreversible control servomechanisms power the control surfaces and are in turn controlled by the pilot through mechanical linkages. The lateral-directional control system consists of outer wing section ailerons, center wing section spoiler-slot-deflectors, and a conventional rudder. The two horizontal stabilizers, one on each side of the tail fuselage, are collectively known as the Unit Horizontal Tail (UHT) and provide coordinated pitch control. The lateral and longitudinal systems respond to autopilot inputs, and the rudder is stabilized. Series trim is introduced into the rudder and aileron signal linkages and parallel trim inputs are introduced into the UHT linkage. Mechanical springs, bobweights, and viscous dampers provide artificial feel and control-stick centering forces.[3]

Hydraulic power is supplied by two independent power control systems designated PC1 and PC2. The PC1 and PC2 systems have separate hydraulic lines, reservoirs, and engine driven pumps. Under normal operating conditions both systems supply pressure to tandem actuators in the flight control system. If either PC system fails the other should supply adequate power for flight. If both PC systems fail and the emergency power package (EPP) fails to restore PC1 pressure, the UHT will move trailing edge down to a zero tail angle of attack giving an aircraft nose down pitch. Airframe Change Number 50 inserts check valves at the inlet ports of the UHT actuators to delay this UHT movement. In addition, Airframe Change

Number 15 moves the hydraulic lines in the aft section of the aircraft further apart and protects the UHT actuators with armor plate.

Fluid flows from the PC1 and PC2 hydraulic pumps through the system pressure lines into the actuating cylinders, and from the cylinder return ports into the system return lines. Hydraulic components are protected from overpressure by a pressure relief valve. Fluid returns to the PC1 and PC2 reservoir and hydraulic pumps separately.

The PC1 system has a surge damper/accumulator to absorb pressure surges in the lines and to maintain pressure in the return line when main system pressure drops below 1800 psi. This accumulator is precharged to 1500 psi with nitrogen by the accumulator precharge system and is charged with hydraulic fluid by means of the system pressure line.

If system pressure drops below 1800 psi a pressure sensitive check valve between the surge damper/accumulator and the system pressure line closes to maintain the accumulator pressure. This in turn pressurizes the fluid reservoir to provide inlet pressure for the hydraulic pump in the emergency power package. If the PC1 system fails due to a line leak, the EPP cannot supply pressure to the flight controls because the EPP uses the PC1 system hydraulic lines.

The PC2 system powers the nose gear steering, wheel brakes, landing gear, arresting gear, leading and trailing edge flaps, wingfold, and catapult launch bar. In addition, this system powers the other half of the flight control tandem actuators.

The utilities circuit is separated from the flight controls by an isolation valve manually controlled by the flap handle. When this valve is closed a leak in the utilities will not cause a loss of pressure in the power control system. A return line check valve prevents fluid back flow into the utility circuits and possible loss of PC2 supply system fluid even with the isolation valve closed.[4]

III. SYSTEM ANALYSIS

The description of the present A7A/B hydraulic system indicates that its redundancies are adequate for peace-time operation. However, experiences with the F-105, F4-B and RA5C aircraft have shown redundancies such as these to be inadequate for combat operations.[1]

The NATOPS Flight Manual for the A7A/B aircraft states: "Complete loss of power control system hydraulic pressure may result in an uncontrollable nose down pitch and high negative-g forces. If loss of both power control systems is evident and the EPP will not restore PC1 pressure, abandon the aircraft prior to complete loss of pressure and resulting negative-g pitch-down. Consider placing the left hand on alternate ejection handle if delaying ejection to the last minute. Following uncontrollable pitch, g forces may exceed pilot capability to successfully eject. Airframe Change No. 50 installs check valves at the UHT actuators to reduce the violence of the pitchover. This provides the pilot a more favorable g environment for ejection and gives him more time to eject."[4]

The first problem was to determine the most probable envelope within which the backup flight control system must operate. Initial assumptions were that upon sustaining battle damage consisting of partial or full hydraulic failure, the pilot will jettison all stores and armaments to initiate a return to a safe area. The aircraft then has a clean configuration of about 23, 000 pounds gross weight of which approximately 5000 pounds is fuel.

The usual range of combat altitudes is from 3000 feet to 15,000 feet above mean sea level. During anti-aircraft missile evasion, sea level altitudes are occasionally encountered. It is at these altitudes that the aircraft has a high probability of damage from anti-aircraft gun fire. The altitude envelope was chosen to be sea level to 15,000 feet. The airspeed envelope is from 200 knots to 450 knots or Mach .3 to Mach .7. Two hundred knots could be experienced at the apogee of a poorly executed pop-up bombing maneuver and 450 knots is a likely bomb release airspeed. A cruise-in airspeed would be within this airspeed bracket.

With the flight envelope defined, it was then necessary to determine the hinge moment for the UHT at representative points in the flight envelope. The hinge moment (HM) was calculated using the following equations:

(1) $HM = C_H \, q \, S_T \, \bar{c}_T$

(2) $C_H = C_{H_{it}} \, \alpha_T$, the hinge moment coefficient.

(3) $S_T \; \bar{c}_T = 134.5 \text{ feet}^2$ per panel, a constant which includes the tail efficiency factor.

(4) Tail angle of attack (α_T) = $\alpha_{FUS} - \epsilon + i_t$, where i_t is the tail incidence angle.

Figures (1), (2) and (3)[5] were combined to give Figure (4), Downwash (ϵ) as a Function of Mach Number (M) and Fuselage Angle of Attack (α_{FUS}). Figure (4) made it possible to determine downwash as a function of fuselage angle of attack and Mach Number.

Values for the fuselage angle of attack and tail incidence angle were taken from Reference 6, pages A-4 and A-5. These values

were plotted versus Mach Number to give Figures (5) and (6) for sea level and 15,000 feet altitude respectively. $C_{H_{it}}$ taken from Figure (7)[5] was already a function of altitude and Mach Number.

Using Figures (4), (5), (6) and (7) all variables were specified as functions of altitude and Mach Number. A negative tail angle of attack gives a negative tail lift producing a positive aircraft pitching moment and tail hinge moment.

A solution for the tail hinge-moment problem consisted of first using equation (4) to find the tail angle of attack. Fuselage angle of attack and the tail incidence angle were extracted from Figures (5) or (6) depending on altitude. Downwash was determined using Figure (4) with Mach Number and fuselage angle of attack specifying the variable. Figure (7) was used to find $C_{H_{it}}$ as a function of altitude and Mach Number.

With all variables defined as a function of a given altitude and Mach Number, equation (1) was solved. Results of these calculations are in Appendix A in tabular form. Note that the tail hinge moment equation was solved for Mach Numbers from 0.3 to 0.8 and for two altitudes, sea level and 15,000 feet.

The tail angle of attack is negative for all cases and with a complete hydraulic failure the UHT would assume a zero angle of attack giving zero tail lift and a consequent nose down pitching moment to the aircraft. The hinge moment is a maximum at sea level, therefore sea level figures were used to determine power requirements for the UHT. Mach 0.7 was selected as the upper limit for the speed envelope prior to finding that the hinge moment more than doubled from Mach 0.7 to Mach 0.8 at sea level.

FIGURE 1

A-7A DOWNWASH

CRUISE CONFIGURATION

NO STORES

RIGID AIRPLANE

M=.18

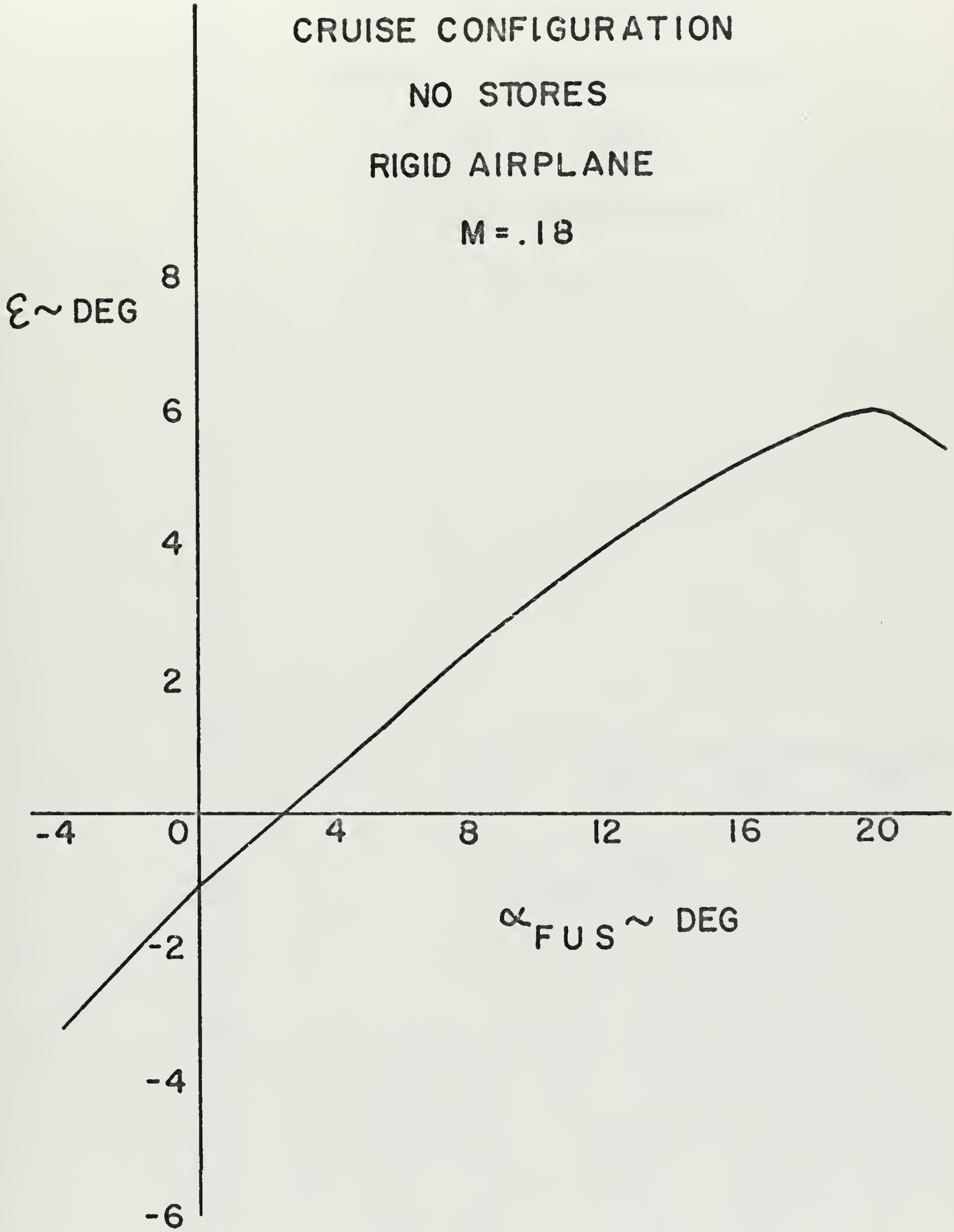


FIGURE 2

A-7A DOWNWASH
CRUISE CONFIGURATION
NO STORES
RIGID AIRPLANE
M = .6

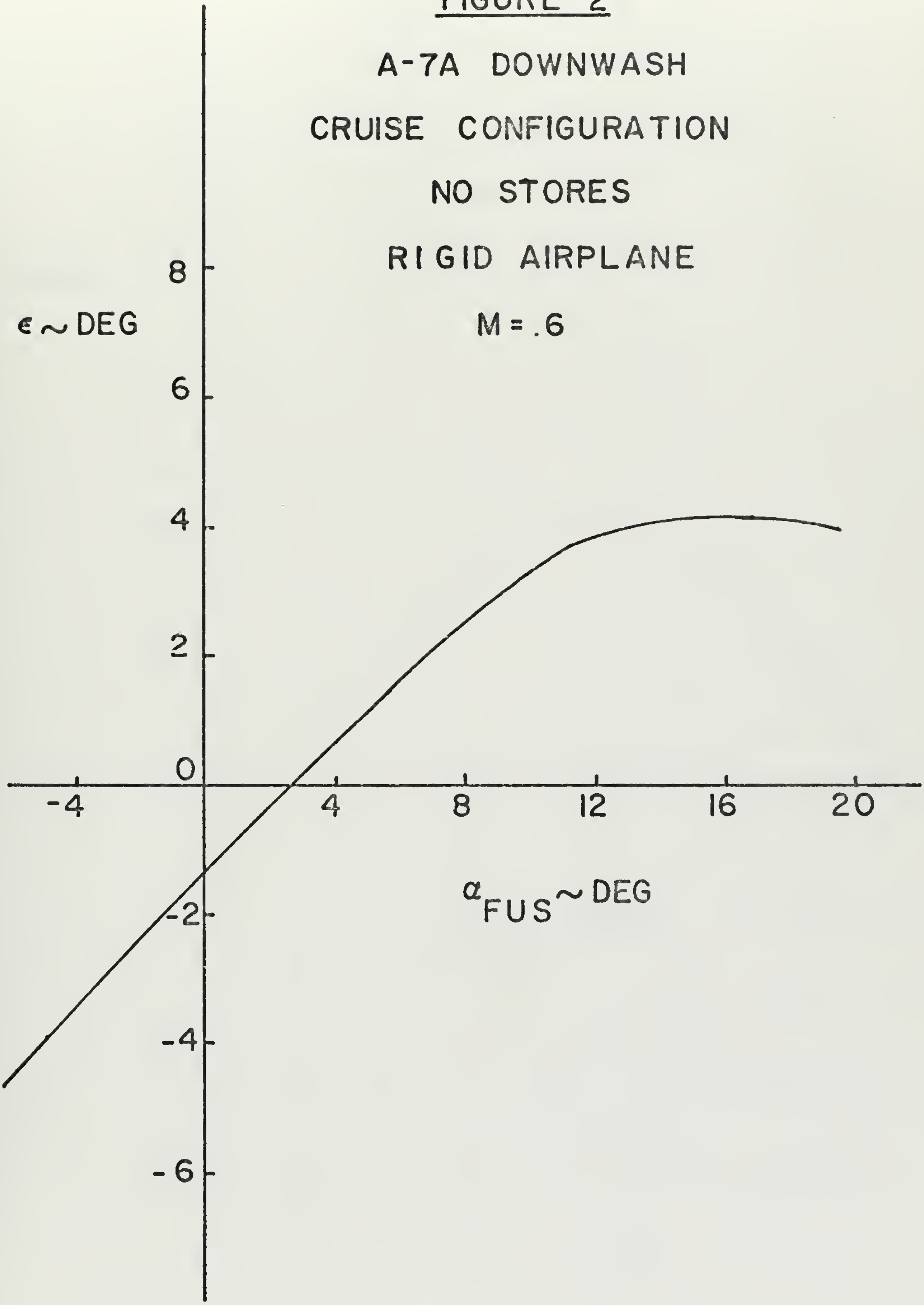


FIGURE 3

A-7A DOWNWASH

CRUISE CONFIGURATION

NO STORES

RIGID AIRPLANE

M = .8

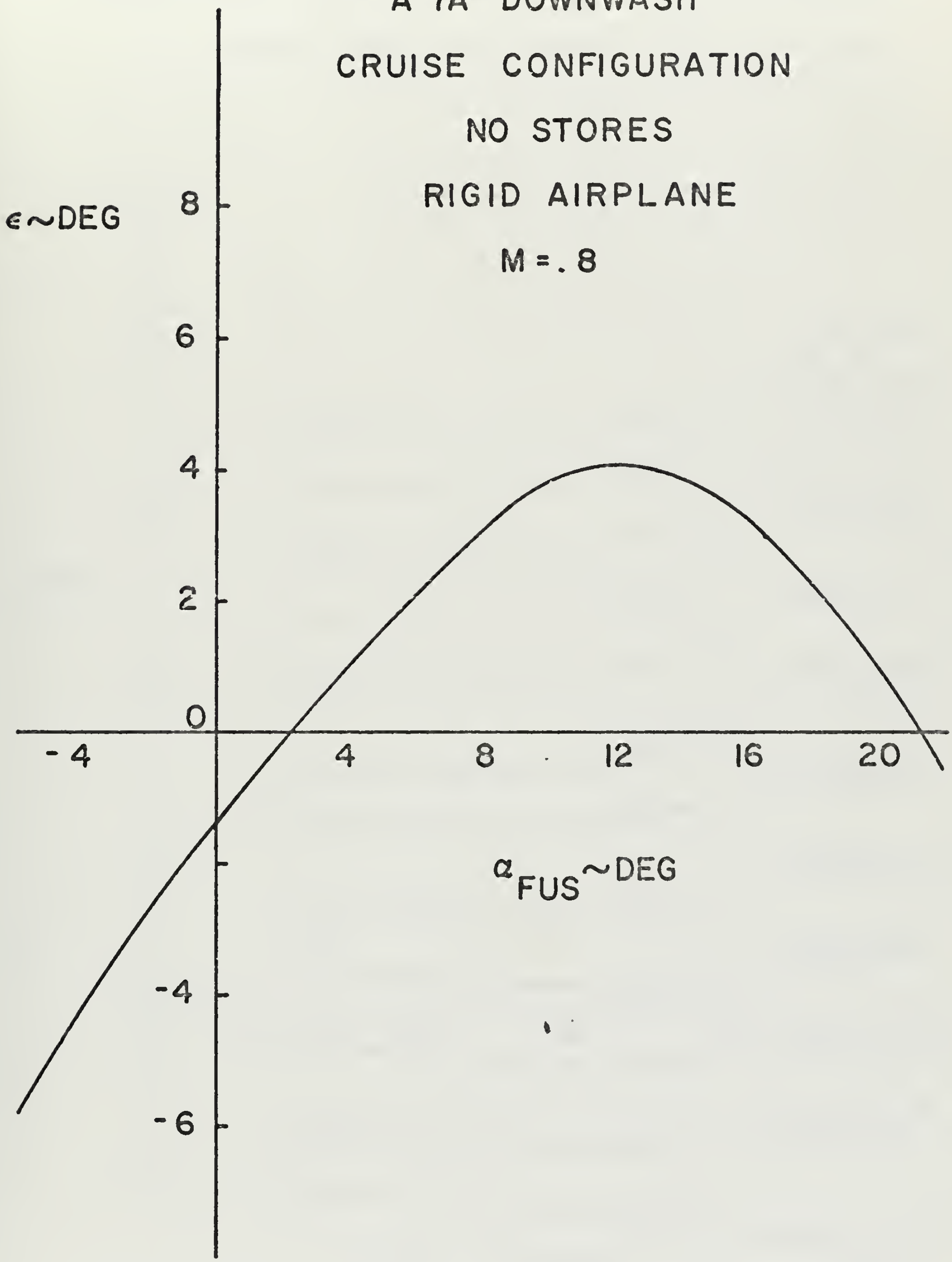
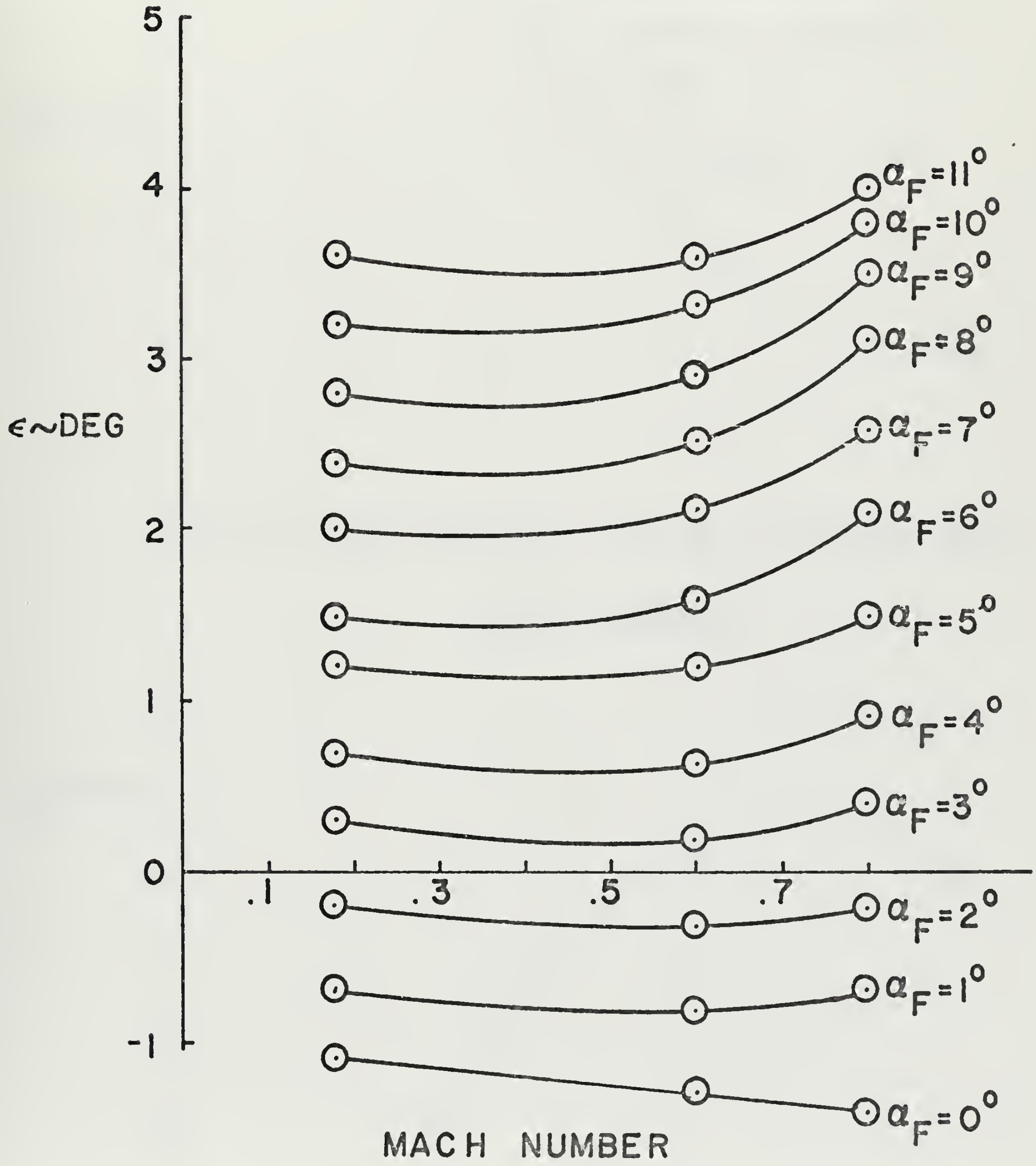


FIGURE 4

DOWNWASH AS A FUNCTION OF MACH NUMBER AND FUSELAGE ANGLE OF ATTACK



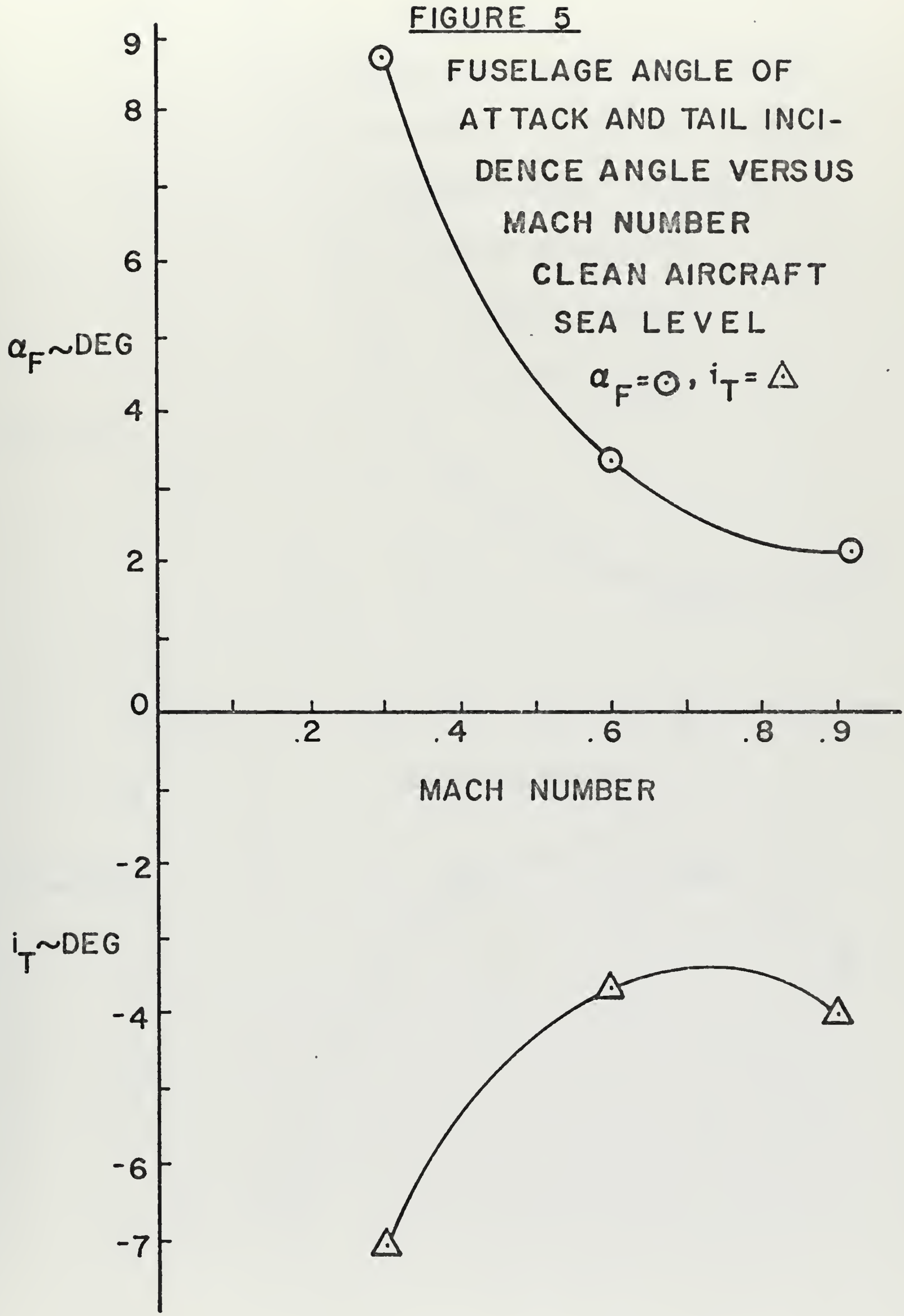


FIGURE 5
FUSELAGE ANGLE OF ATTACK AND TAIL INCIDENCE ANGLE VERSUS MACH NUMBER
CLEAN AIRCRAFT
SEA LEVEL
α_F = ⊙, i_T = △
α_F ~ DEG
i_T ~ DEG
MACH NUMBER
9
8
6
4
2
0
-2
-4
-6
-7
.2
.4
.6
.8
.9

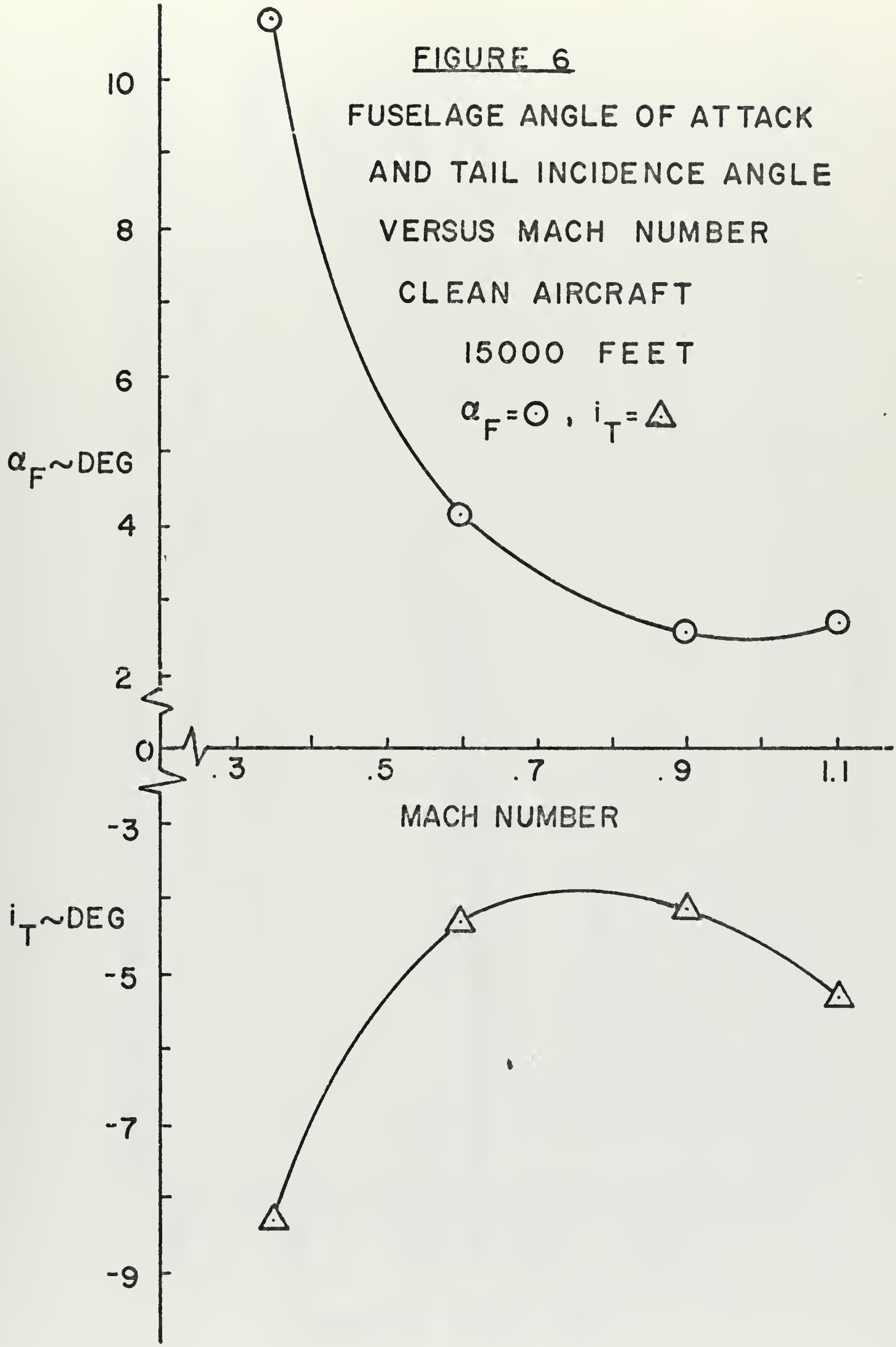
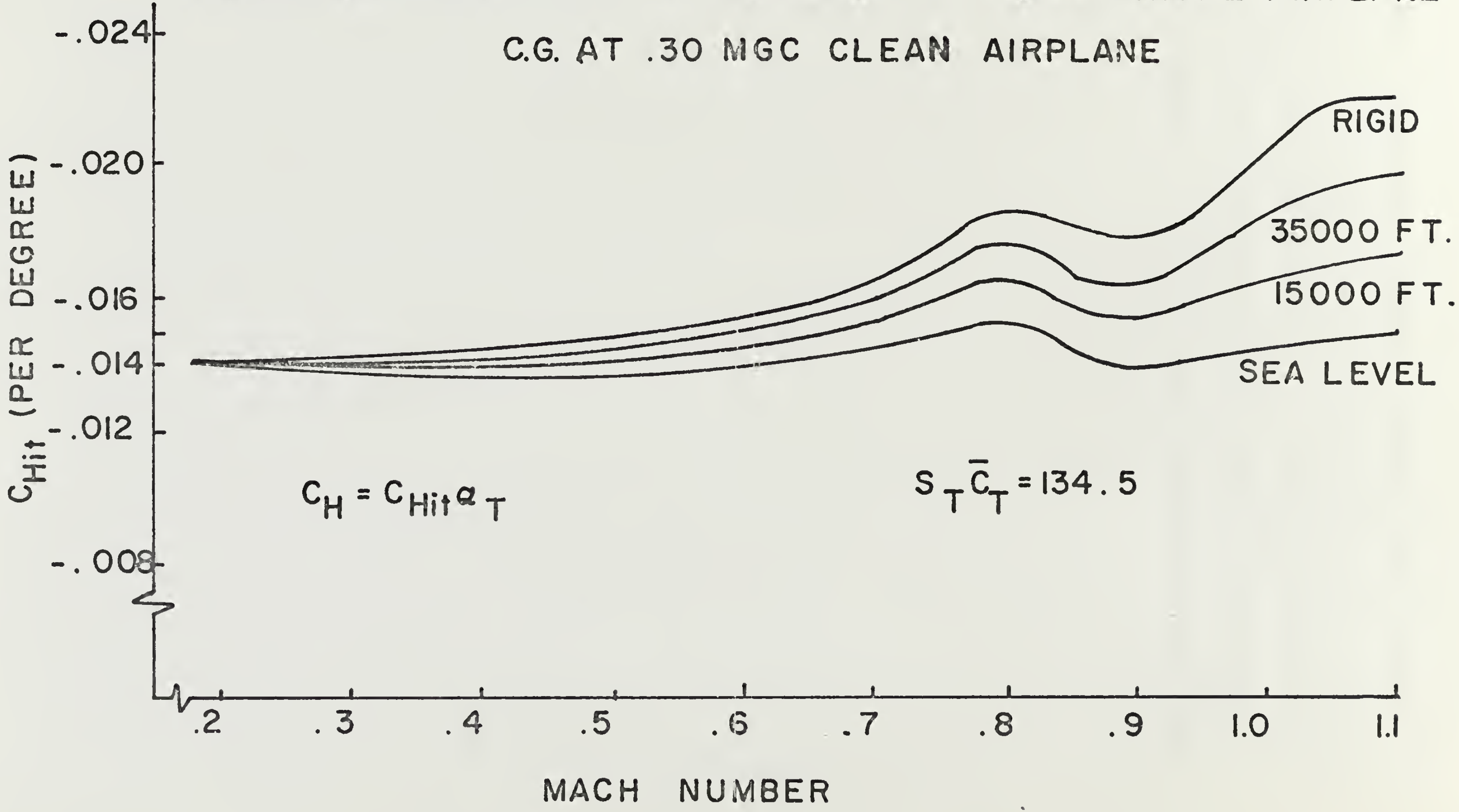


FIGURE 6
FUSELAGE ANGLE OF ATTACK
AND TAIL INCIDENCE ANGLE
VERSUS MACH NUMBER
CLEAN AIRCRAFT
15000 FEET
α_F = ⊙ , i_T = △
α_F ~ DEG
10
8
6
4
2
0
-3
-5
-7
-9
i_T ~ DEG
.3
.5
.7
.9
1.1
MACH NUMBER

FIGURE 7

HORIZONTAL STABILIZER HINGE MOMENT OF THE FLEXIBLE AIRPLANE

C.G. AT .30 MGC CLEAN AIRPLANE



From Appendix A it can be seen that the tail hinge moment increases with airspeed and decreases with altitude. The maximum tail hinge moment of interest was calculated to be 1900 foot-pounds and occurred at sea level at Mach 0.7. This hinge moment would have to be overcome or neutralized by the backup flight control system if the system is to fulfill the flight envelope requirements.

IV. ELECTRICAL SOLUTION TO DESIGN PROBLEM

Originally it was hoped that by simply rearranging some aircraft components and adding a little additional electrical wiring a useable backup control system could be developed at very little cost with practically no addition to the weight of the aircraft. Further investigation revealed that the trim motors envisioned as being capable of moving control surfaces were inadequate for this purpose as they were designed as simple servo motors used for positioning hydraulic actuators. These trim motors did not have enough power to directly position a control surface.[7]

Additional solutions to the problem were considered such as an asymmetric thrust reverser,[2] or a third hydraulic system as used in the A7E. The first system was rejected because it necessitated total redesign of the engine and airframe. This would be costly and would mean a large increase in weight. The third hydraulic system concept was investigated thoroughly but only as a last resort because of the added weight. In addition it was desired to make the backup flight control system completely independent of hydraulics. Since a manual backup system was out of the question for the UHT, an electrical system seemed to be the answer.

The aircraft generator has a 25KVA power generating capacity and the emergency power package (EPP) is capable of producing 2.5 KVA. The aircraft generator and EPP produce 33.5 horsepower and 3.35 horsepower respectively. To calculate the horsepower rating of the required electrical motor to drive the UHT, a control

surface rate of movement of 5 degrees per second was considered to be adequate but this figure was doubled to provide a conservative solution until such time as the system could be tested on an analog computer.[8, 9]

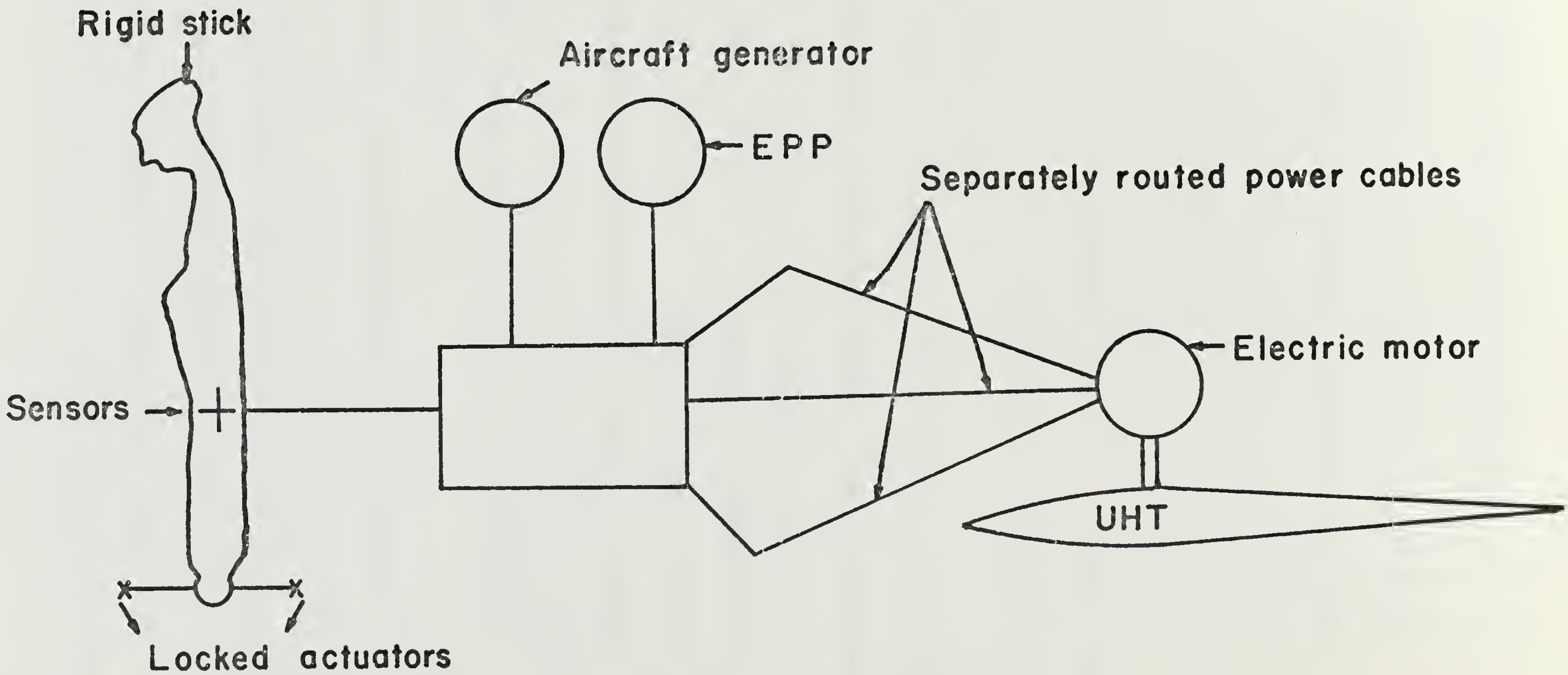
Using maximum values of the hinge moment and a 10 degree per second control surface rate of travel it was determined that a 0.603 horsepower electric motor would adequately handle the hinge moment. Therefore even with a relatively low-efficiency electric motor there is sufficient power available from the EPP to power the proposed UHT drive.

Figure (8) shows the proposed backup flight control system. The control stick in the A7 could be used to control the movement of the UHT as in normal flight. It is suggested that the control stick be set up as a rigid, force controller[10] with strain gage sensors. For backup operations control power would be supplied to the UHT electric motor at a rate proportional to the force sensed by the control stick sensors. A modification would be required to the automatic flight control system so that with a loss of hydraulic pressure the longitudinal automatic flight control system actuators would lock in a neutral position giving a longitudinally rigid stick.[11]

Power to the system would be supplied by either the aircraft generator or the EPP. In addition it should be noted that a minimum of three different electric control cables lead to the electric motor. These cables would be routed to the electric motor over widely dispersed paths so as to ensure backup control system redundancy.

FIGURE 8

BLOCK DIAGRAM OF PROPOSED BACKUP FLIGHT CONTROL SYSTEM



V. CONCLUSIONS AND RECOMMENDATIONS

For simplicity all calculations were made assuming that the UHT acts as one unit. Actually both halves of the UHT move independently but synchronously. Therefore two motors of half the calculated horsepower are required for each half of the UHT. The two motors must be synchronized but this presents no problem. Because of the restrictors present in the UHT actuators, the electric motors would not have to assume the UHT load from the normal hydraulic system instantaneously.

It would appear that this longitudinal backup system would permit the aircraft to land even with a hydraulic failure. Lateral-directional controls should also be considered and with the reserve electrical power remaining even from the EPP it is feasible to operate either the ailerons or rudder electrically. The ideal solution would be to operate the rudder manually by cables using a hydraulic disconnect system similar to that in the A-4 aircraft. This would permit the pilot to work only against aerodynamic loads, not the hydraulic linkage and actuators as well.

The rigid stick control was selected because this means of control seems to permit better tracking or more precise control of the aircraft without interference from the normal control system components. In addition this method should enable the pilot to put in smoother inputs to the UHT motors, and permit a rapid shift from the moving stick conventional system to the emergency backup system.

It would be useful to set up the equations of motion for the A7 aircraft on an analog computer and try several tracking problems with the backup flight control system. An optimum figure for the rate of UHT movement could be derived as well as the behavior of this system in turbulence. Electrical control of ailerons or manual control of the rudder could be simulated and the ability of the pilot to land using the backup system could be determined.

It appears that an electrical or an electrical/manual backup flight control system for the A7A/B aircraft is not only desirable from a safety standpoint, but practical from an engineering standpoint.

APPENDIX A

UHT HINGE MOMENT DATA

CLEAN AIRCRAFT, SEA LEVEL

M	q(Lb/Ft^2)	i_T(DEG)	α_F(DEG)	ϵ (DEG)	α_T(DEG)	C_{Hit}(per DEG)	UHT HINGE MOMENT(per panel) (Ft-Lbs)
.3	133.52	-7.10	8.73	2.70	-1.07	-.0137	263.243
.4	237.36	-5.85	6.60	1.85	-1.10	-.0136	477.598
.5	370.88	-4.60	4.80	1.10	-.90	-.0136	610.565
.6	534.06	-3.64	3.29	.30	-.65	-.0140	653.664
.7	726.92	-3.15	2.30	-.18	-.67	-.0145	949.838
.8	949.44	-3.15	1.80	-.30	-1.05	-.0152	2038.090

CLEAN AIRCRAFT, 15000 FEET

M	q(Lb/Ft^2)	i_T(DEG)	α_F(DEG)	ϵ (DEG)	α_T(DEG)	C_{Hit}(perDEG)	UHT HINGE MOMENT(per panel) (Ft-Lbs)
.35	102.64	-8.34	10.77	3.50	-1.07	-.0140	206.792
.4	134.06	-6.75	8.20	2.50	-1.05	-.0140	265.047
.5	209.46	-5.15	5.50	1.40	-1.05	-.0141	417.094
.6	301.63	-4.28	4.13	.70	-.85	-.0145	500.006
.7	410.54	-3.85	3.30	.40	-.95	-.0153	802.595
.8	536.22	-3.80	2.80	.20	-1.20	-.0165	1428.008

LIST OF REFERENCES

1. Air Force Flight Dynamics Laboratory Technical Report AFFDL-TR-70-48, Requirements for Minimum Backup Flight Control Systems, by Eugene E. Yore, p. 1-6, 18, 21, 36, October, 1970.

2. Longstaff, T. W., A Manual Stand-by Control System for Tactical Fighter Aircraft Through the Use of an Asymmetric Thrust Reverser, Masters Thesis, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, 1969.

3. Vought Aeronautics Division, LTV Aerospace Corporation, Report No. 2-51724/5R-5131, A-7 Flight Control Systems Design Report, by M. R. Skinner and C. Welgehausen, p. 78-100, September, 1965.

4. Commander, Naval Air Systems Command, NAVAIR 01-45AAA-1, NATOPS Flight Manual A-7A, A-7B Aircraft, p. 1-40 to 1-52 to 1-82, 5-31, 15 August 1969.

5. Figures received with letter of 13 April 1971 from Mr. W. C. Heald, Unit 2-53362, Vought Aeronautics Co., LTV Aerospace Corporation.

6. Vought Aeronautics Division, LTV Aerospace Corporation, Report No. 2-53320/7R-5326, A-7B Estimated Flying Qualities (U), by J. D. Etheridge, p. A-4, A-5, 14 December 1967.

7. Brite, R. J. and Fioranelli, C. H., Synchros and Servos, Howard W. Sams & Co., Inc., 1967.

8. Vought Aeronautics Division, LTV Aerospace Corporation, Report No. 2-53560/9R-5448, Final Engineering Report Automatic Flight Control System for A-7D/E Aircraft (U), by R. A. Jeske and R. P. Anderson, p. 9, 28-33, 50, undated.

9. Friedman, M. H. and Rosenblatt, J., Direct and Alternating Current Machinery, McGraw-Hill Book Company, Inc., p. 84-85, 1963.

10. Caswell, D. W., Development of a Simulator for the Evaluation of Rigid and Moveable Aircraft Controls, Masters Thesis, Naval Postgraduate School, Monterey, California, June, 1969.

11. Blakelock, J. H., Automatic Control of Aircraft and Missiles, John Wiley & Sons, Inc., p. 63, 1965.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor Donald Layton, Code 57Ln Department of Aeronautical Engineering Naval Postgraduate School Monterey, California 93940	1
4.	LCDR Charles C. Cromer Naval Air Systems Command Naval Plant Representative Office LTV Aerospace Corporation P. O. Box 5907 Dallas, Texas 75222	1
5.	LCDR R. J. Miles, USN VA-127 Naval Air Station Lemoore, California 93245	1
6.	Chairman, Department of Aeronautics Naval Postgraduate School Monterey, California 93940	1

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A Feasibility Study for a Backup Flight Control System for the A7A/B Aircraft

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; September 1971

5. AUTHOR(S) (First name, middle initial, last name)

Richard Jeffrey Miles

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1971	30	11

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

The hinge moments for the A7A/B unit horizontal tail (UHT) were computed for a range of airspeeds and altitudes representative of the Southeast Asia combat environment. Electrical power available from the aircraft generator and the emergency power package was determined. The horsepower required to overcome the maximum hinge moment of the UHT was calculated and compared with power available from the aircraft generator and the emergency power package in order to ascertain whether an electrical motor could control UHT movement.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Control Systems						
Fly-By-Wire						

Thesis 129117
M58518 Miles
c.1 A feasibility study
for a backup flight
control system for the
A7A/B aircraft.